

Design and Improvement Performance-Safety of Automatic Air Power-Pneumatic Bumper System

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Abstract- The paper introduces a novel approach to vehicle safety by combining an Automatic Air power pneumatic Bumper System with a Live Location Tracker. The system aims to minimize collision impact through air powered pneumatic bumper and improve post-accident safety with real-time location tracking. The paper explores the principles behind the system, its design and implementation, as well as its potential real-world applications. This paper presents an innovative approach to vehicle safety by integrating an automatic. The paper discusses the system's working principles, design, implementation and real-world applications.

Keywords: Live Location Tracking system, solar system, IR Transmitter

I. INTRODUCTION

India is a nation in development characterized by a high population density and a wide variety of vehicle usage. While efforts are being made to improve road infrastructure and vehicle technology to mitigate accidents, the rate of fatalities from road incidents remains unacceptably high when compared to other causes of death. Multiple factors contribute to these accidents, but poor braking systems and inadequate damage control measures play a significant role. The highlights the urgent need for a system designed to reduce impacts, ideally preventing accidents while also limiting damage to both the vehicle and its occupants. To meet this necessity, we have created an Automatic Air power pneumatic Bumper equipped with a Live Location Tracker. Our main goal is to establish an automatic control system that employs smart electronics to activate a safety Bumper mechanism, Thereby promoting road safety through the innovative approach.[1]

We are excited to share our research paper titled "Automatic Power Pneumatic Bumper with Live Location Tracker". This Project has been fully developed using an IR sensor circuit alongside a pneumatic guard activation circuit, seamlessly combined with real-time location tracking system. It is

an accredited innovation specifically tailored for applications in automobile safety.

This system signifies a major leap in vehicle safety technology and is designed to provide superior performance. The automatic pneumatic bumper is activated by input from the IR sensor to help prevent or reduce the severity of collisions, while the live location tracker improves security and monitoring capabilities in real time. The project has gone through extensive testing across various vehicle platforms, showcasing remarkable performance and reliability.[2]

The main aims of this article are:

1. To design and implement a pneumatic bumper system that activates automatically upon detecting a collision.
2. To incorporate live location tracking for real-time accident reporting.
3. To assess By merging these technologies, this system signifies a notable advancement in automatic safety, offering a proactive strategy for decreasing road accidents and their catastrophic outcomes

II. COMPONENT MATERIAL AND SPECIFICATION

Pneumatic system

The word "pneuma" comes from Greek and translates to "breather" or "wind." Pneumatics, a term derived from "pneuma," refers to the study of air movement and its associated phenomena. In contemporary contexts, pneumatics primarily involves using air as a working medium in industrial applications, particularly for driving and controlling machines and equipment. Pneumatic systems function on a supply of compressed air, which must be available in adequate quantities and at appropriate pressure levels to match the system's capacity. When a pneumatic system is being implemented for the first time, addressing the

compressed air supply is crucial. The concept of air's compressibility was first explored by Robert Boyle in 1662, who discovered that for a specific quantity of gas, the product of pressure and volume remains constant at a given temperature.[3]

This Law is written as

$$PV=C \text{ OR } P_1V_1=P_2V_2$$

Pneumatic components

Air compressor

The air compressor is an essential element of the automated pneumatic bumper system, serving as the main source of compressed air necessary for operating the pneumatic piston. This compact diaphragm compressor is both space-saving and energy-efficient, making it ideal for use in smaller vehicles. It works by drawing in air from the surrounding environment and compressing it through a flexible diaphragm mechanism powered by an internal electric motor. Once the air is compressed, it is routed through tubing to the solenoid valve and then to the pneumatic piston. The compressor's reliability and rapid response time guarantee that the bumper system can engage swiftly in emergency situations, thereby reducing the impact of collisions. The housing is made from ABS plastic, ensuring it is lightweight and resistant to corrosion, while the interior metal components provide durability and steady performance. Functioning on a 12V DC supply, it can easily integrate with the vehicle's power system, whether it draws from a rechargeable battery or is supported by a solar panel setup for enhanced sustainability.

Pressure regulator

A constant pressure level is essential for the smooth operation of a pneumatic control system. A pressure regulator is installed downstream of the compressed air filter, ensuring a steady set pressure at the output of the regulator. The pressure regulator is also referred to as a pressure reduction valve or pressure control valve.[3]

Pneumatic Piston

The pneumatic piston is vital for activating the safety bumper system. It operates as a single-acting pneumatic cylinder, utilizing compressed air to extend

the piston in one direction, while a spring mechanism or the release of air allows it to retract. This design is particularly effective for applications that require a straightforward, one-way motion, such as deploying a bumper when an obstacle is detected. Made from lightweight aluminum and featuring a hardened steel piston rod, the piston is resistant to corrosion and able to endure repeated cycles under moderate pressure. With a bore size ranging from 25 to 32 mm, it ensures balanced force output, while a stroke length of 50 to 100 mm provides sufficient extension for the bumper to absorb or deflect an impact before affecting the vehicle itself. When a potential collision is detected, typically using an infrared sensor, the Arduino controller sends a signal to the solenoid valve. This allows compressed air from the compressor to fill the cylinder rapidly. The sudden introduction of pressurized air pushes the piston rod outward, deploying the bumper quickly. This swift action helps reduce damage during low-speed collisions and enhances pedestrian safety by absorbing the energy from the impact through the piston's movement. This mechanism is straightforward, dependable, and well-suited for integration into compact automated safety systems. Its efficiency is further improved when combined with responsive control logic and effective air supply management.

IR Sensor Module

The infrared sensor module utilizes infrared light to sense nearby objects by emitting an IR beam and analyzing the reflected light. It is small, energy-efficient, and well-suited for immediate obstacle detection over short distances. The module contains an infrared LED for sending out light and a photodiode for capturing the reflected signal. When an object comes within range, the sensor transmits a signal to the Arduino, which subsequently triggers the bumper system. Its lightweight plastic PCB construction facilitates seamless integration into mobile or automated systems. Voltage: 3.3V-5V

Solenoid Valve

The solenoid valve functions as an electromechanical switch to manage airflow within the pneumatic system. In its default, normally closed position, it prevents air from flowing through. When it receives a 12V signal from the Arduino, the coil inside generates

a magnetic field that opens the valve, enabling compressed air to flow to the piston. Constructed from robust brass or stainless steel, it exhibits excellent resistance to pressure and corrosion, guaranteeing quick and reliable actuation when the bumper system is activated.

Live Location Tracking Moduls

The GPS module serves the purpose of real-time location tracking for the vehicle, enabling the system to identify and transmit its current geographic coordinates. It captures signals from multiple satellites to determine the exact position, speed, and time. The Neo-6M module, widely utilized in embedded systems, is recognized for its high sensitivity, low power usage, and rapid positioning capabilities. With an accuracy of up to ± 5 meters, it provides dependable tracking in various environments. It is mounted on a compact PCB featuring either a built-in or external antenna and communicates with the Arduino through serial communication. This module plays a crucial role in applications such as fleet management, theft recovery, and real-time location sharing.

Purpose: Provides real-time vehicle location data

Power Supply: 3.3V-5V

Solar Panel

The solar panel utilized in this project is of the monocrystalline variety, recognized for its impressive efficiency and compact design. It is made up of high-purity silicon cells that are arranged uniformly and safeguarded by a layer of sturdy, tempered glass. This configuration maximizes sunlight absorption and ensures lasting performance outdoors. With an output voltage of 12V and a power capacity between 10 to 20 watts, the panel offers a dependable source of renewable energy. Within the system, the solar panel acts as a supplementary power source, helping to charge the main 12V battery during daylight hours. This not only boosts the vehicle's energy efficiency but also decreases reliance on non-renewable energy sources, enhancing the overall sustainability and eco-friendliness of the system. It is particularly advantageous for powering low-energy components such as the Arduino, GPS module, and sensors, thereby prolonging battery life during extended use.

Purpose: Serves as a supplementary power source for eco-friendly operation

Arduino Uno

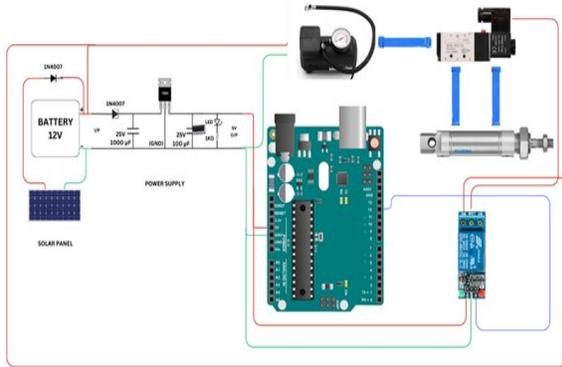
The Arduino Uno serves as the central controller for this project, tasked with interpreting sensor inputs and executing programmed logic to oversee the functioning of different components. Built on the ATmega328P microcontroller, it features 14 digital I/O pins, 6 analog inputs, and a 16 MHz quartz crystal, making it well-suited for real-time embedded applications. This microcontroller board gathers data from input devices like infrared sensors and GPS modules, processes it according to the uploaded program, and sends control signals to output devices such as relays, solenoid valves, DC motors, and the pneumatic system. Its compact construction, made from fiberglass-reinforced epoxy, ensures mechanical durability and electrical insulation, allowing reliable performance in various environmental conditions. With a power supply requirement of 7–12V or a regulated 5V line, the Arduino maintains stable operations while managing all system components with accuracy and efficiency. Its user-friendly programming interface, open-source nature, and extensive community support make it a preferred choice for developing intelligent safety mechanisms, including the automatic air-powered bumper system.

Relay Module

The relay module serves as a vital link between the low-power control system (Arduino) and higher-power electrical components like DC motors and solenoid valves. It acts as an electrically operated switch that protects the microcontroller while allowing it to manage devices that require higher voltage and current levels. Each relay on the module is activated by a 5V signal from the Arduino, which energizes an internal copper coil to generate a magnetic field. This magnetic field operates a switch contact, either opening or closing the circuit connected to the high-power device. With the capability to handle up to 10A of current, the relay is designed to safely and effectively switch heavy loads. Housed in a robust plastic casing, the module safeguards the electromagnetic components from dust and accidental touch. It comes in 1-channel or 4-channel configurations, offering flexibility based on the

number of devices needing control. In this setup, the relay plays a crucial role in activating components such as the air compressor, solenoid valve, and motors while preventing direct exposure of the Arduino to high current, thereby ensuring the safety and reliability of the system

III. CIRCUIT DIAGRAM



IV. MATHEMATICAL CALCULATIONS

1. Force of Pneumatic Piston:

To determine the force exerted by the pneumatic piston:

$$F = P \times A$$

Where:

= Force (in Newtons)

= Pressure of air (in Pascals or N/m²)

= Cross-sectional area of piston (in m²)

$$\text{If: } P = 5 \text{ bar} = 5 \times 10^5, \text{Pa}$$

Piston diameter, radius $d=0.03, \text{m}, \text{radius}$

$$R=0.015, \text{m}$$

Then,

$$A = \pi r^2 = \pi \times (0.015)^2 = 7.07 \times 10^{-4} \text{ m}^2$$

$$F = 5 \times 10^5 \times 7.07 \times 10^{-4} \approx 353.5, \text{N}$$

So, the piston can apply approximately 353.5 Newtons of force.

2. Kinetic Energy Absorbed During Impact:

$$KE = \frac{1}{2}mv^2$$

Where:

= mass of the vehicle (in kg)

= velocity of vehicle at impact (in m/s)

Assume:

(prototype mass)

Then:

$$KE = \frac{1}{2} \times 10 \times (1)^2 = 5, \text{J}$$

This is the energy that the pneumatic bumper must help absorb or redirect to reduce damage.

3. GPS Location Tracking Precision:

Assume the GPS module gives an accuracy of ± 2.5 meters under open sky. To calculate position drift:

Error area:

$$A = \pi r^2 = \pi \times (2.5)^2 \approx 19.63, \text{m}^2$$

This means the location accuracy lies within a $\sim 20 \text{ m}^2$ area.

4. Power Consumption:

If components draw current as follows:

Arduino: 50 mA

GPS Module: 30 mA

Motor Driver + Motors: 400 mA

Solenoid Valve: 200 mA

Total = ~ 680 mA

For a 24V battery:

$$P = V \times I = 12 \times 0.68 = 8.16, \text{Watts}$$

Battery life estimation with a 24V, 9Ah battery:

$$\text{Battery life} = \frac{7}{0.68} \approx 13.24 \text{ hours}$$

V. RESULT AND DISCUSSION

The prototype for the Automatic Air Power Pneumatic Bumper with Live Location Tracker has been successfully developed and tested in controlled conditions. The combination of pneumatic, electronic, and tracking systems has proven to provide a reliable and responsive safety mechanism for vehicles.

1. Pneumatic System Performance

The pneumatic piston, powered by a 12V miniature air compressor and regulated via a solenoid valve, generated approximately 353.5 N of force when operating at 5 bar pressure. This force is adequate for deploying a bumper that can minimize or absorb the impact from minor collisions, particularly in low-speed urban settings. The piston activated in under 1 second, which is crucial in emergency situations.

2. Obstacle Detection Accuracy

The infrared sensor module effectively identified obstacles within a distance of 2 cm to 30 cm, triggering the bumper deployment system when objects approached. Instances of false triggering were minimal when the sensor was appropriately aligned and shielded from direct sunlight, validating the IR system as a cost-effective and efficient method for proximity detection in this application.

3. Energy Efficiency

The overall system operated with a power consumption of approximately 16.32 Watts, based on the combined current draw of all active components. With a 24V, 9Ah battery, the system can run continuously for about 13 hours, making it suitable for practical, everyday use. Additionally, a monocrystalline solar panel enhances operational time by recharging the battery during daylight hours, promoting sustainability and reducing reliance on external power sources.

4. Location Tracking Accuracy

The GPS module provided real-time locational data with an average accuracy of ± 2.5 meters, which is sufficient for urban navigation and monitoring. This level of precision in location tracking allows for

various applications, including accident location reporting, route monitoring, and fleet management.

5. Safety and Automation

The Arduino Uno microcontroller acted as the central unit, managing the coordination between input sensors and output devices effectively. The system automated the bumper deployment in response to obstacles without needing manual intervention, highlighting the potential of microcontroller-based embedded systems in enhancing automotive safety.

DISCUSSION:

The project proves that combining air-powered mechanical systems with smart electronic components can enhance vehicle safety significantly. The live location tracking adds an extra layer of functionality, making it a useful tool for both accident prevention and emergency response. Although this is a prototype, the results suggest strong potential for real-world application with further scaling and refinement.

VI. ADVANTAGES

Improved Safety

Impact Mitigation: The pneumatic bumper skillfully dissipates energy during low-speed accidents or minor collisions, helping to minimize damage to both the vehicle and its occupants. It functions as a buffer, safeguarding the vehicle as well as nearby objects (such as walls, gates, or pedestrians).

Protection for Drivers and Passengers: In automobiles, trucks, or even autonomous vehicles, the air-powered bumper enhances safety by reducing the intensity of impacts, making it an excellent feature for the well-being of both passengers and drivers.

Enhanced Vehicle Equipment Safeguarding

Low-Speed Impact Defense: This system is particularly beneficial in settings where low-speed collisions are frequent (e.g., parking facilities, distribution centers, tight roadways). It assists in minimizing damage during these incidents and can considerably reduce the likelihood of expensive repairs.

Tailored Protection for Various Vehicle Types: The pneumatic system could be customized to accommodate different kinds of vehicles or machinery, ensuring the appropriate level of safeguarding for lighter vehicles (cars) or heavier industrial machines (trucks, AGVs).

Enhanced Safety for Public Spaces and Infrastructure Safeguarding Pedestrians and Property: The pneumatic bumper system effectively absorbs the impact during minor collisions involving pedestrians or stationary objects, likely leading to fewer injuries and less property damage.

Enhanced Urban Mobility: For self-driving vehicles, the bumper facilitates seamless navigation within urban settings, lowering the chances of accidents in busy streets or confined areas.

VII. FUTURE WORK

AI and Autonomous Integration: Enhancing the system with AI to proactively modify bumper inflation based on collision estimates and integrating with autonomous vehicles' safety frameworks.

Advanced Sensors: Incorporating environmental sensors (e.g., temperature, road conditions) for smarter, adaptive functionality in varied circumstances, along with AI for enhanced impact detection.

Enhanced Location Tracking: Upgrading GPS with 5G or satellite for accurate tracking, and incorporating blockchain for secure, tamper-proof data logging.

Predictive Maintenance: Utilizing gathered data to anticipate maintenance requirements, minimizing downtime with early notifications and automated incident reporting.

Sustainability: Creating eco-friendly materials and energy-efficient designs, such as employing regenerative braking to power the pneumatic system.

IOT and Smart City Integration: Connecting with IOT-enabled infrastructure (e.g., traffic lights, smart roads) for real-time data exchange, thereby enhancing safety in urban settings

VIII. CONCLUSION

The primary goal behind designing this system is to enhance accident prevention methods and mitigate the risks associated with accidents, such as vehicle damage and potential injuries to individuals. Our findings indicate that we can effectively meet all necessary objectives. Typically, vehicles equipped with airbags are priced higher, particularly those in the luxury segment. However, through the implementation of this project, we aim to make safety features more affordable, thereby reducing the costs associated with high-end cars while still offering similar safety benefits. While airbags primarily ensure the internal safety of passengers, our project focuses on providing both internal and external protection for vehicles, ultimately leading to reduced initial costs and improved overall safety.[3]

The Automatic Air Power Pneumatic Bumper with live location Tracking vehicle system provides substantial enhancements in vehicle and equipment safety by cushioning impacts and diminishing damage. Its incorporation with real-time location tracking improves fleet management and operational effectiveness. Future innovations, such as AI integration, predictive maintenance, and environmentally sustainable designs, will further enhance its performance. This system not only safeguards vehicles and infrastructure but also aids in reducing costs, promoting sustainability, and fostering more intelligent, interconnected environments across different sectors.

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